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Energy Procedia 18 (2012) 644 – 651
Energy Procedia

# Calibration of Angstrom equation for estimating Solar Radiation using Meta-Heuristic Harmony Search Algorithm (Case study: Mashhad-East of Iran)

Isaac Rahimi[a]*, Bahram Bakhtiari[b], Kourosh Qaderi[b], Mehrdad Aghababaie[c], a*

[a] *Department of Water Engineering, College of Agriculture, Young Researchers Society, Shahid Bahonar University of Kerman, Kerman, Iran*
[b] *Department of Water Engineering, College of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran*
[c] *Department of Electronic Engineering, Engineering Faculty, Shahid Bahonar University of Kerman, Kerman, Iran*

**Abstract**

The solar radiation received by earth surface is one of the most applicable parameter that is usable in hydrology, agriculture, climatology and meteorological modeling. Many different experimental equations had been suggested by researchers to estimate this parameter in different climates. In this paper, Meta-Heuristic Harmony Search Algorithm (HS) has been developed for determining the Angstrom equation coefficients, by using the daily solar radiation and daily sunshine duration data of Mashhad Synoptic station from 1993 to 2007 (4765 daily data). Also the Angstrom equation coefficients have been estimated for all the month. 70٪ of data used for train and 30٪ of them for test. Three statistical parameters Root Mean Square Error (RMSE), Index of agreement (d) and Mean Bias Error (MBE) have been used to estimate error and model validation. The results showed that, the value of RMSE, d and MBE for HS algorithm were 0.1265, 0.8323 and -0.0280, respectively. The value of Angstrom coefficients for Mashhad station in HS method is 0.4743 (for b coefficient) and 0.2657 (for a coefficient). The value of correlation in this method is obtained (R= 0.9047).



*Keywords*: Solar radiation, Angstrom equation, Sunshine hours, Harmony Search.

## 1. INTRODUCTION

Knowledge of solar radiation on the earth's surface is required for many applications. In many applications of solar energy by solar engineers, architects, meteorologists, agriculturists and hydrologists a reasonably accurate knowledge about the availability of solar resources is a prerequisite at any desired site [1, 2].

The amount of global solar radiation is one of the primary variables for determining solar energy production in a region. It is Depending on the latitude, altitude and many meteorological factors [3]. The simple model used to estimate daily global solar radiation on horizontal surface is the modified form of the Angstrom-type equation. The original Angstrom type regression equation related monthly average daily radiation to clear day radiation at the location in question and average fraction of possible sunshine hours [2]. The first correlation between the global solar irradiation and the sunshine duration was first exhibited by Angstrom (1924) using a simple linear model[4], but later, Prescott [5] put this equation in a more convenient form by replacing the monthly global irradiation on a clear day by the monthly average daily extraterrestrial radiation, $H_0$ as:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \tag{1}$$

* Corresponding author. Tel.: +98-341-3202662; Fax: +98-341-3202043.
*E-mail address*: *Isaac.Rahimi@Gmail.com* (I. Rahimi).

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Where $a$ and $b$ are the model coefficients; H, S and $S_0$ are the daily global irradiation, daily sunshine duration and maximum possible daily sunshine duration, respectively. These ratios ($H/H_0$ and $S/S_0$) vary between zero and one. From a mathematical point of view $a$ is the intercept and $b$ is the slope parameter of a straight line expression. Physically, if the sky is completely clear, then the meteorological and astronomical sunshine durations become equal to each other ($S=S_0$) and consequently, Eq. (1) yields a+b=1. Many articles have been published for the efficient estimation of model parameter from available data [5], (Prescott, 1940 [5]; Rietveld, 1978 [6]; Gopinathan, 1988 [7]; Lewis, 1989 [8]; Akinoeglu and Ecevit, 1990 [9]; Wahab, 1993 [10]; Hinrichsen, 1994 [11]).

The extraterrestrial solar radiation on a horizontal surface ($H_0$) explained as the short-wave solar radiation in the absence of an atmosphere, is a well-behaved function of the day of the year, time of day, and latitude. For daily (24-hour) periods, $H_0$ can be calculated from the solar constant, the solar declination, and the day of the year [12]:

$$H_0 = \frac{24}{\pi} G_{sc} d_r [\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \tag{2}$$

Where, $H_0$ is extraterrestrial radiation [MJ $m^{-2}d^{-1}$], $G_{sc}$ is solar constant [4.92 $MJm^{-2}h^{-1}$], $d_r$ is inverse relative distance factor (squared) for the earth-sun [unitless], $w_s$ is sunset hour angle (radians), $\varphi$ is latitude (radians), and $\delta$ is solar declination (radians) [12-13].

The latitude $\varphi$ is positive for the Northern Hemisphere, negative for the Southern hemisphere and $\delta$ is calculated as [12-13]:

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365} J\right) \tag{3}$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365} J + 1.39\right) \tag{4}$$

Where, $J$ is the number of the day of the year starting from the first of January.

The coefficients of the Angstrom–Prescott equation were calculated from regression analysis between $H/H_0$ and $n/N$ for each day. Regression were then made to obtain final estimates for the coefficients $a$ and $b$ for each day. These parameters are calculate for all the sites available in a region, then according to the climatologically and geographical similarities, the coefficients at other locations are adjusted subjectively by expert experiments. Finally, the sunshine data at these places can be used to generate the values of the global irradiation with the help of Eq.1 [1]. Since the Angstrom's publications, numerous evaluations of $a$ and $b$ coefficients have been made for various locations [14,15]. Several authors have suggested the convenience of a monthly data partitioning in the Angstrom–Prescott values calibration [14, 16, 17]. Numerous methods are suggested to estimate Rs, including those based on generation from stochastic weather models [18], satellite image [19], linear interpolation [20], artificial neural network (ANN) [21] and physical transfer processes [22].

Recently many kind of meta-heuristic algorithm are used in optimization problem. Few applications of meta-heuristic methods to solve solar energy problems have been reported, Genetic Algorithm (GA) is one of these methods. Sen et al. (2001) [1] has been used application of the GA method for determination of the Angstrom equation coefficients. One of the meta-heuristic algorithm are used in optimization problem, the meta-heuristic Harmony Search (HS) optimization algorithm, which is imitating the music improvisation process where musicians improvise their instruments' pitches searching for a perfect state of harmony, was developed by Geem et al. (2001)[23,24].The HS algorithm has been recently applied to various engineering optimization problems including traveling salesman problem (Geem et al., 2001) [24], optimization of the river flood model (Kim et al., 2001) [25], optimum design of water distribution network (Geem, 2006) [26], optimum design of truss structures (Lee and Geem, 2004)[27] and the simultaneous determination of aquifer parameters and zone structures by an inverse solution algorithm (Ayvaz, 2007)[28].

The objective of this study is to present the application of the Harmony Search Algorithm (HS) for determination of the Angstrom equation coefficients variability for each month separately in an objective manner, Mashhad synoptic station east of Iran by using the daily solar radiation and sunshine duration data.

## 2. Harmony search algorithm (HS):

A meta-heuristic algorithm, mimicking the improvisation process of music players, has been recently developed and named harmony search (HS) [24]. The HS algorithm proposed by Geem et al. (2001) [24] is a met-heuristic optimization algorithm and a new HS meta-heuristic algorithm was conceptualized using the musical process of searching for a perfect state of harmony [27, 29]. In this improvisation process, members of the musical group try to find the best harmony as determined by an aesthetic standard, just as the optimization algorithm tries to find the global optimum as determined by the objective function. HS algorithm presenting several advantages with respect to traditional optimization techniques such as the following [27]: (a) HS algorithm imposes fewer mathematical requirements and this algorithm does not require initial values and uses a random search instead of a gradient search, so derivative information is unnecessary. (b) The HS algorithm generates a new vector, after considering all of the existing vectors, whereas the genetic algorithm (GA) only considers the two parent vectors [29]. The HS algorithm parameters that are required to solve the optimization problem; Harmony Memory Size (HMS) that represents the number of solution vectors in the harmony memory (HM); Harmony Memory Considering Rate (HMCR) that is the probability of assigning the values to the variables from HM; Pitch Adjusting Rate (PAR); and the number of improvisations (NI) that represents the number of iterations or stopping criterion (Lee et al., 2005), (Lee and Geem, 2004)[23,27,29,31].The optimization procedure of the HS algorithm, consists of Steps 5, as follows [27]:
Step1. Initialize the optimization problem and algorithm parameters.
Step2. Initialize the harmony memory (HM).
Step3. Improvise a new harmony from the HM.
Step4. Update the HM.
Step5. Repeat Steps 3 and 4 until the termination criterion is satisfied

*Step 1: Initialize the optimization problem and algorithm parameters.* First, the optimization problem is specified as follows [27, 28]:

$$\text{Minimize} \quad f(x) \text{ subject to } x_i \in Xi = 1, 2, \ldots, N \tag{5}$$

Where $f(x)$ is the objective function, $x$ is the set of each decision variable $x_i$ and $Xi$ is the set of possible range of values of $N$ decision variable. The HS algorithm parameters, HMS, HMCR, PAR and NI that are required to solve the optimization problem (i.e., Eq. (5)) are also specified in this step. Here, HMCR and PAR are parameters that are used to improve the solution vector [28].

*Step2. Initialize the harmony memory (HM).* In this step, the ‘‘harmony memory’’ (HM) matrix, shown in Eq. (2), is filled with randomly generated solution vectors as the HMS and sorted by the values of the objective function, f(x).

$$HM = \begin{bmatrix} x_1^1 & x_1^1 & \ldots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \ldots & x_{N-1}^2 & x_N^2 \\ . & . & . & . & . \\ . & . & . & . & . \\ x_1^{HMS-1} & x_2^{HMS-1} & \ldots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \ldots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \tag{6}$$

*Step3. Improvise a new harmony from the HM.* Generating a new harmony is called improvisation. New harmony vector, X'= ($X'_1$, $X'_2$ … $X'_N$) is generated from the HM based on memory considerations, pitch adjustments, and randomization. The pseudo code of the harmony improvisation strategy is as follows [27]:

For each i ∈ [1,N] do

If U (0,1) ≤ HMCR than /* *memory consideration**/

$x'_i = x^i_j$, where j ~ U (1, 2, . . . , HMS).

If U (0,1) ≤ PAR then /* pitch adjustment*/

$x'_i = xi \pm r \times bw$, where r ~ U (0, 1) and bw is an arbitrary distance bandwidth.

Endif

else/* random selection */

$x'_i = LB_i + r \times (UB_i - LB_i)$, ($LB_i$ and $UB_i$ are the lower and upper bounds for each decision variable, respectively)

endif

*(4) Step 4. Update the HM*. In Step 4, if the new harmony vector is better than the worst harmony in the HM in terms of the objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

(5) Step 5. *Repeat Steps 3 and 4 until the termination criterion is satisfied*. In Step 5, the computations are terminated when the termination criterion is satisfied. If not, Steps 3 and 4 are repeated [27].

In this paper, the HS procedure is applied to Eq. (1) for estimating the Angstrom coefficients for given irradiation and sunshine duration data.

## 3. Materials and Methods

### *3.1. Case study*

In Mashhad's special geographical situation, interfacing different weather fronts make it such a region with a special different continental climate. Overall, its climate is as mid dry and cold with dry hot summers and wet-cold winters. The maximum annual temperature is about $+35^0$ C and the minimum is about $-15^0$ C. The annual average precipitation is about 253 mm. This station is located at 36º 16' Northern latitude, 59º 38' Eastern longitude and 999.2 meter elevation. The daily data of solar radiation and sunshine duration prepared from The Islamic Republic of Iran Meteorological Organization (IRIMIO). The Mashhad synoptic station has daily data over a 15 year period from 1993 to 2007. In general, daily global radiation and sunshine duration measurement considered for the HS algorithm application in this paper. For this algorithm, 70٪ of data have been used to train, and 30٪ of them for test.

### *3.2. Performance indicators*

In the literature, there are numerous statistical methods available to compare the models of solar radiation estimation. The most widely used statistical indicators are relative, correlation coefficient (*R*), index of agreement (d), Mean Bias Error (MBE) and Root Mean Square Error (RMSE) [32], (Ma and Iqbal 1984 [33]; Akinoglu and Ecevit 1990 [34]; Tiris et al. 1996 [35]; Ertekin and Yaldiz 2000 [36]; Ulgen and Hepbasli 2003 [37]). In the present study, these statistical indicators are used to evaluate the accuracy of estimating the Angstrom equation parameters. They are calculated as:

$$RMSE = \left[ \frac{1}{N} \sum_{i=1}^{N} (P_i - O_i)^2 \right]^{\frac{1}{2}} \tag{7}$$

$$d = 1 - \left[ \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} [(P_i - O_{avg}) + (O_i - O_{avg})]^2} \right] \tag{8}$$

$$MBE = \left[ \frac{1}{N} \sum_{i=1}^{N} (P_i - O_i) \right] \tag{9}$$

Where $P_i$ is estimated or calculated data; $O_i$ is observed data, $O_{avg}$ is mean value of the observed data. Lower values of MBE and RMSE indicate a better model performance; the unit of them is (MJ $m^{-2}$ $d^{-1}$). Perfect agreement would exist between $P_i$ and $O_i$ if d=1.

**4. Results and Discussion:**

The HS algorithm was coded with MATLAB 2010(a). The sensitivity analysis of the HS model is performed with different combinations of each parameter. Here, we make a sensitivity analysis only to find suitable initial values of the parameters for better performance in our problem because these parameters directly influence the solution accuracy. Hence, Sensitivity analyses were examined for varying user-specified parameters of HS such as: HMCR, bw and NI, the value of this parameters are 0.9, 0.1 and 1000, respectively. For this case HMS and PAR parameters are fixed at 40 and 0.5, respectively. Each user-specified parameter combination was tested 10 times. In general, *a* had the variability of 26%, varying from 0.2553 to 0.3212 (0.2828± 0.020), followed by *b* with variability of 50%, varying from 0.4030 to 0.6028 (0.4715 ±0.066), whereas sum (a + b) had the variability of 25%, varying from 0.700 to 0.8780 (0.7609 ± 0.057). The values of R ranged from 0.80 to 0.95 (0.88 ± 0.053).The results in terms of various performance statistics from the HS and GA methods for all historical period data are presented in Table 1. The result of this comparison show that the values of *RMSE*, *d* and *R* for both of these methods are the same but MBE parameter the result of HS algorithm is better than GA algorithm. The values of the Angstrom coefficient for each season are presented in Table 2. *b* coefficient has been increased from spring to winter. The minimum and maximum value of RMSE is 0.0808 for spring and 0.1456 for summer, respectively. R and MBE for all season to some extent is the same but *d* in summer is better than other season. According to Table 2 the average values of *a* and *b* in this table have the same value of the HS performance of them in 1 but average of RMSE has a smallest than RMSE in Table 1.

Table 1. Comparison of the result runs of HS and GA method

| Algorithm | b | a | RMSE | R | d | MBE |
|---|---|---|---|---|---|---|
| HS | 0.4743 | 0.2657 | 0.1265 | 0.9047 | 0.8323 | -0.028 |
| GA | 0.4783 | 0.2763 | 0.1267 | 0.9047 | 0.8321 | -0.0331 |

*a* and *b* are the Angstrom coefficient, *RMSE* is Root Mean Square Error (MJ $m^{-2}$ $d^{-1}$), R is correlation coefficient, d is index of agreement, MBE is Mean Bias Error (MJ $m^{-2}$ $d^{-1}$).

Table 2. The result of HS method performance for each season.

| Season | b | a | RMSE | R | d | MBE |
|---|---|---|---|---|---|---|
| Spring | 0.4670 | 0.2795 | 0.0808 | 0.9591 | 0.8806 | -0.0047 |
| Summer | 0.4795 | 0.2618 | 0.1456 | 0.9643 | 0.9021 | -0.0034 |
| Autumn | 0.4801 | 0.2691 | 0.1186 | 0.9486 | 0.8393 | -0.0066 |
| Winter | 0.4817 | 0.2722 | 0.1255 | 0.9501 | 0.8576 | -0.0047 |
| Mean | 0.4770 | 0.2756 | 0.1176 | | | |

*a* and *b* are the Angstrom coefficient, *RMSE* is Root Mean Square Error (MJ $m^{-2}$ $d^{-1}$), R is correlation coefficient, d is index of agreement, MBE is Mean Bias Error (MJ $m^{-2}$ $d^{-1}$)

The result of HS algorithm for each month is presented in Table 3, its graph has shown in Fig 1 (a) and the result of GA performance is presented in Table 3 and its graph has shown in Fig 1 (b). The value of statistical parameter in HS algorithm for most of month is better than GA. In February, March, April, September and December for both of algorithm, the same value of *a* and *b* have been calculated. The minimum and maximum value of *b* coefficient for both of algorithm has been obtained in July and January (Fig 1 (a)). The minimum and maximum value of *a* coefficient for both of algorithm has been obtained in July and February (Fig 1 (b)). According to Fig 1 (a), *b* coefficient in HS and GA methods for February, March, April, September and December has the same value. The average values of *b* and *a* in Table 2 and Table 3 approximately are the same with respect to the value of them in Table 1.

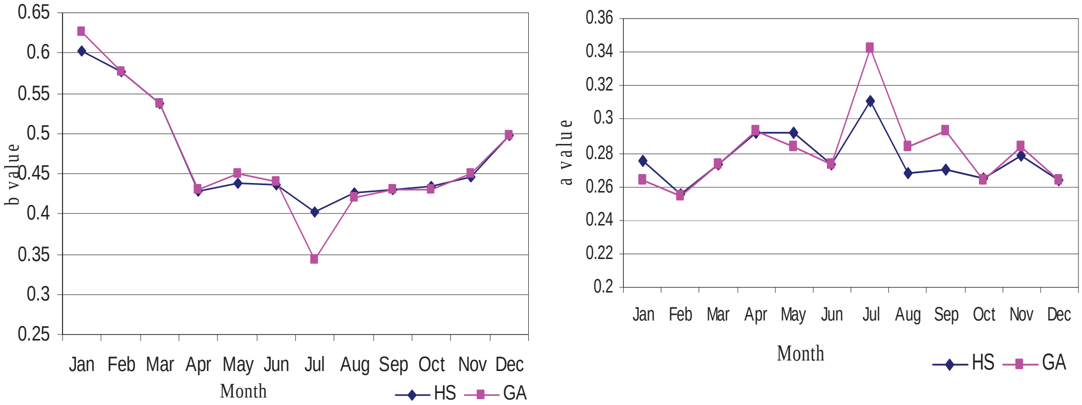


Fig 1. (a) *b* value of GA and HS; (b) *a* value of GA and HS

Table 2 Result of HS algorithm for each month

| Month | b | a | RMSE | R | d | MBE | a+b |
|---|---|---|---|---|---|---|---|
| January | 0.6028 | 0.2752 | 0.1151 | 0.9514 | 0.9328 | 0.013 | 0.8780 |
| February | 0.5768 | 0.2553 | 0.1301 | 0.9192 | 0.8991 | -0.0129 | 0.8321 |
| March | 0.5376 | 0.2737 | 0.107 | 0.9322 | 0.91.5 | -0.0034 | 0.8113 |
| April | 0.4289 | 0.2920 | 0.0987 | 0.9079 | 0.8153 | -0.0271 | 0.7419 |
| May | 0.4382 | 0.2918 | 0.0921 | 0.9345 | 0.8372 | -0.0237 | 0.7300 |
| Jun | 0.4365 | 0.2733 | 0.0766 | 0.8864 | 0.8358 | -0.0257 | 0.7098 |
| July | 0.4030 | 0.3110 | 0.0673 | 0.8302 | 0.8352 | -0.0236 | 0.714 |
| August | 0.4257 | 0.2676 | 0.0752 | 0.8068 | 0.8902 | -0.028 | 0.7033 |
| September | 0.4303 | 0.2702 | 0.1136 | 0.8011 | 0.9028 | -0.036 | 0.7362 |
| October | 0.4351 | 0.2649 | 0.1021 | 0.8304 | 0.9028 | -0.036 | 0.7000 |
| November | 0.4453 | 0.2786 | 0.1251 | 0.8936 | 0.9022 | -0.0458 | 0.7239 |
| December | 0.4985 | 0.2639 | 0.1293 | 0.8389 | 0.8745 | -0.0939 | 0.7624 |
| Mean | 0.4715 | 0.2773 | | | | | |

*a* and *b* are the Angstrom coefficient, *RMSE* is Root Mean Square Error (MJ $m^{-2} d^{-1}$), R is correlation coefficient, d is index of agreement, MBE is Mean Bias Error (MJ $m^{-2} d^{-1}$).

Table 2 Result of GA algorithm

| Month | b | a | RMSE | R | d | MBE | a+b |
|---|---|---|---|---|---|---|---|
| January | 0.6256 | 0.2639 | 0.1185 | 0.9514 | 0.9377 | 0.0345 | 0.8895 |
| February | 0.5767 | 0.2542 | 0.1304 | 0.9192 | 0.899 | -0.019 | 0.8309 |
| March | 0.5376 | 0.2737 | 0.108 | 0.9322 | 0.8985 | -0.0029 | 0.8113 |
| April | 0.4301 | 0.2933 | 0.0995 | 0.9079 | 0.8234 | -0.0534 | 0.7234 |
| May | 0.4497 | 0.2835 | 0.923 | 0.9345 | 0.8393 | -.0413 | 0.7332 |
| Jun | 0.4399 | 0.2737 | 0.0722 | 0.8864 | 0.7349 | -0.0459 | 0.7136 |
| July | 0.3421 | 0.3421 | 0.0721 | 0.8302 | 0.8811 | -0.0415 | 0.6842 |
| August | 0.4203 | 0.2835 | 0.0744 | 0.8068 | 0.8094 | -0.0456 | 0.7038 |
| September | 0.4301 | 0.2933 | 0.1198 | 0.8011 | 0.7278 | -0.081 | 0.7234 |
| October | 0.4301 | 0.2639 | 0.1145 | 0.8304 | 0.8827 | -0.0838 | 0.6940 |
| November | 0.4497 | 0.2835 | 0.1262 | 0.8936 | 0.7529 | -0.0762 | 0.7332 |
| December | 0.4985 | 0.2639 | 0.1239 | 0.8389 | 0.8401 | -0.091 | 0.7624 |
| Mean | 0.4692 | 0.2810 | | | | | |

*a* and *b* are the Angstrom coefficient, *RMSE* is Root Mean Square Error (MJ $m^{-2} d^{-1}$), R is correlation coefficient, d is index of agreement, MBE is Mean Bias Error (MJ $m^{-2} d^{-1}$).

## 5. Conclusion

As can be seen from the simulations summarized above, the heuristic HS algorithm may be effectively used as an optimization technique. This paper has presented an efficient heuristic algorithm, Harmony search algorithm to calculate the Angstrom coefficient for Mashhad East of Iran, showed very good results. According to the statistical test, all the specific monthly equations gave very good results and the values of *RMSE*, *d* and *MBE* are in the acceptable ranges. The difference between monthly, seasonally and annual Angstrom–Prescott coefficients has shown that applying this model should be used or each months separately.

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